

Solar Coronal Structure Study

Final Report

Contract NASW-96005

Period of Performance

11 September, 1996 through 10 August, 2000

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1 Introduction

The subject of this investigation is to study the physics of the solar corona through the analysis of the EUV and UV data produced by two flights (12 May 1992 and 25 April 1994) of the Lockheed Solar Plasma Diagnostics Experiment (SPDE) sounding rocket payload, in combination with *Yohkoh* and ground-based data. Each rocket flight produced both spectral and imaging data. These joint datasets are useful for understanding the physical state of various features in the solar atmosphere at different heights ranging from the photosphere to the corona at the time of the rocket flights, which took place during the declining phase of a solar cycle, 2-4 years before the minimum. The investigation is narrowly focused on comparing the physics of small- and medium-scale strong-field structures with that of large-scale, weak fields.

As we close this investigation, we have to recall that our present position in the understanding of basic solar physics problems (such as coronal heating) is much different from that in 1995 (when we proposed this investigation), due largely to the great success of *SOHO* and *TRACE*. In other words, several topics and techniques we proposed can now be better realized with data from these missions. For this reason, at some point of our work, we started concentrating on the 1992 data, which are more unique and have more supporting data. As a result, we discontinued the investigation on small-scale structures, i.e., bright points, since high-resolution *TRACE* images have addressed more important physics than SPDE EUV images could do.

In the final year, we still spent long time calibrating the 1992 data. The work was complicated because of the old-fashioned film, which had problems not encountered with more modern CCD detectors. After our considerable effort on calibration, we were able to focus on several scientific topics, relying heavily on the SPDE UV images. They include the relation between filaments and filament channels, the identification of hot loops, and the physical conditions of such loops especially

at their foot-points. A total of four papers were completed from this contract, which are listed in the last section.

2 Calibration Activities

The ultimate goal of calibrating the spectral data from the Dual Range Spectrograph (DRSG), as we gradually became convinced, was to make the best use of images taken with the Ultraviolet Filter Camera (UVFC), also referred to as the Transition Region Camera (TRC) or the Ultraviolet Imager (UVI). The images cover much large areas than the DRSG slit. The DRSG calibration was two-fold. First, to locate the slit on solar images, and then to obtain spectra in absolute intensity.

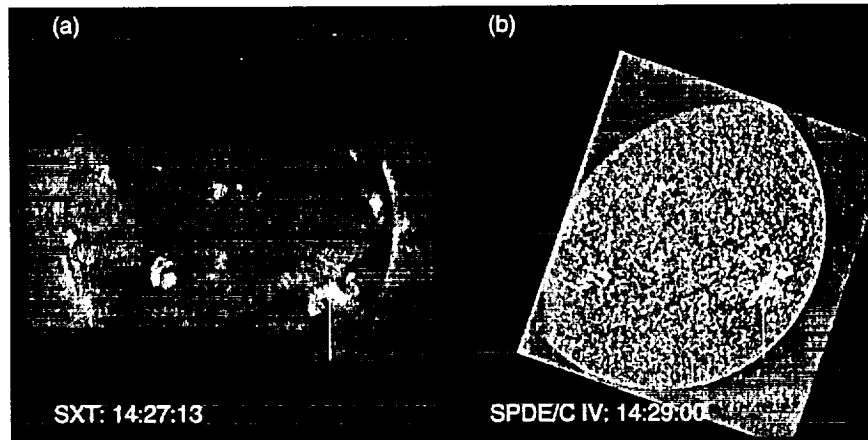


Figure 1: (a) *Yohkoh*/SXT image. (b) SPDE C IV image. Straight lines indicate where the slit of the Dual Range Spectrograph was placed.

The first part was done quite satisfactorily, by putting together all the scattered information as to the possible location of the slit. There were three slit positions, one of which is shown in Figure 1. This position is particularly interesting, since the slit intersects a sunspot.

The second part was more problematic. Some of the line ratios did not seem to be consistent with atomic physics. We first questioned the characterization of the film, and contacted Dr. C. Korendyke at NRL for information on the film that was used for both HRTS and SPDE. The updated exposure-density curve is given in Figure 2. But this re-characterization of the film did not solve the problem. We went back to the original films many times and concluded that strong lines such as the C IV doublet were over-exposed even in the shortest exposure. Therefore, we gave up restoring the intensity of these lines. Instead, we analyzed weaker lines which were not saturated.

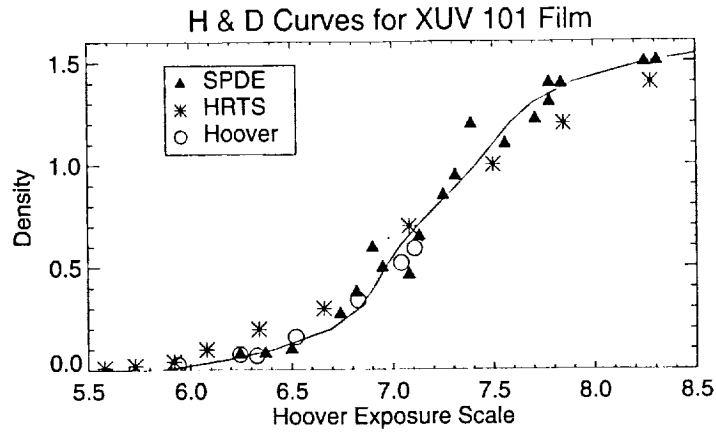


Figure 2: The updated H & D curve for the XUV 101-7 film used for the SPDE/DRSG, in comparison with those of Hoover and HRTS. The line is a polynomial fit to the data.

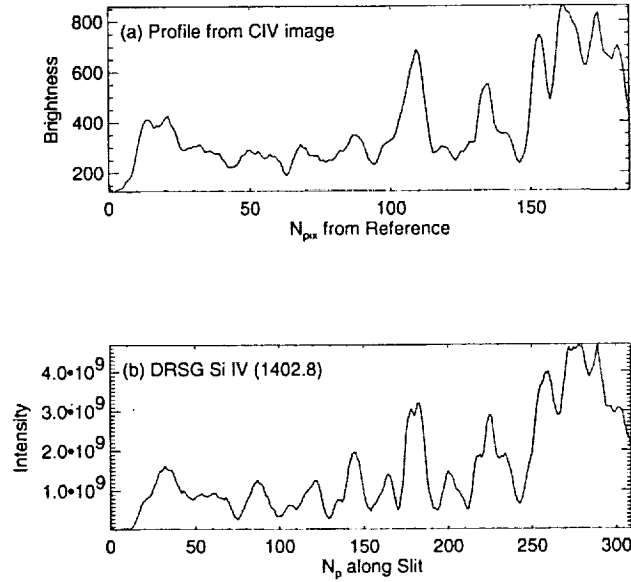


Figure 3: Re-calibrated transmission curves of the two filters used in the SPDE/UVFC. The solid line is for the C IV filter and the dotted line for the continuum filter.

We then compared the positional scan of the Si IV line (1403 \AA , $T=10^{4.8} \text{ K}$, probably unsaturated) with the intensity profile of the C IV image along the line indicated in Figure 1. The comparison is shown in Figure 3. We needed to apply a secondary correction for the DRSG data which showed a gradient towards the limb, presumably as a result of an photographic effect. For a best match, we concluded that

the slit is about 1° rotated from the solar N-S line. Given various uncertainties, we consider the two curves to be in good agreement, suggesting that the SPDE/UVFC C IV images could be used to obtain emission measure of the 10^5 K plasma. This is also consistent with an analysis of *TRACE* UV images. Note that the *TRACE* UV channel was built on the experience of the SPDE/UVFC. Using the algorithm introduced by Handy et al. (1998, *Solar Phys.*, 183, 29), which subtracts from the image in the C IV filter a counterpart in the continuum filters, we get a processed C IV image. But the overall intensity distribution of the processed C IV is not much different from that in the raw image in the similar C IV filter.

3 Active Region Study

First, we just compared the morphology of the target regions as observed by SPDE and *Yohkoh*. It appeared that the region (AR 7154) for the 1992 flight was more interesting, because it was located close to large-scale structures which erupted repeatedly and it was already stable at the time of the SPDE flight despite its sigmodicity. Therefore, our effort was primarily on this region.

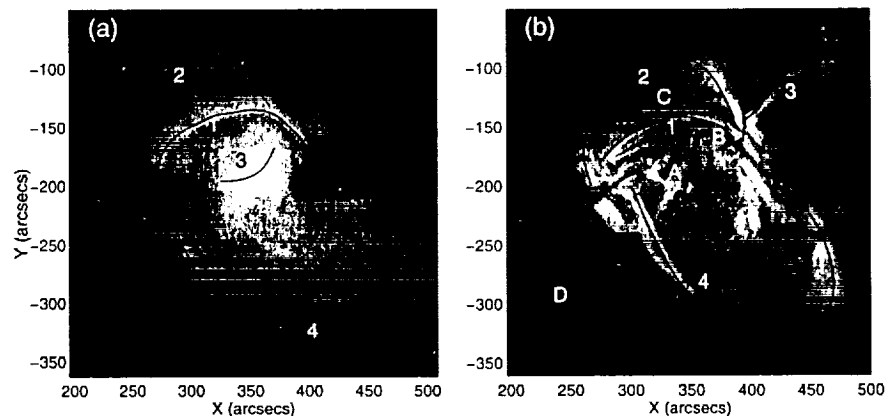


Figure 4: SXT and TRACE 171 Å images of AR 8518, taken on 24 April 1999 at 23:21:32 UT and 23:23:45 UT, respectively. Some representative loops are traced in each image, and some locations of the “moss” are labelled (A–D) in the TRACE image.

Our proposed approach was to calculate the heat deposition at the loop foot-points obtained from the emission measure distribution in UV images, and to compare it with the pressure of SXT loops. Such a comparison is needed to decide between various heating mechanisms. However, the first obvious finding was that there were much more UV bright areas than the probable footpoints of hot SXT loops. Obviously some of the UV bright points would correspond to foot-points of cooler loops not seen

by SXT. As a reference, Figure 4 shows SXT and *TRACE* 171 Å images for a different region, showing that hot ($\gtrsim 3$ MK) and cool (~ 1 MK) loops are not co-spatial.

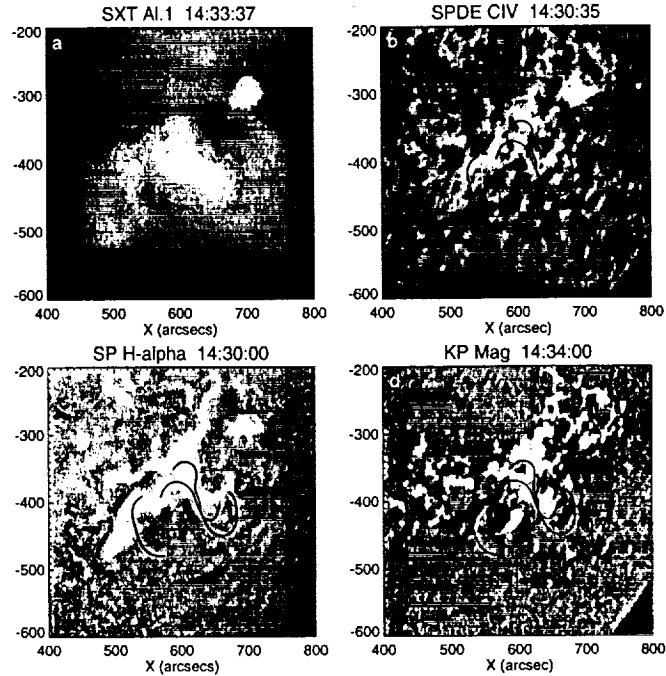


Figure 5: Images of a simple active region. a: soft X-ray image, b: C IV image, c: H α image, and d: line of sight magnetogram. The coordinates are from the disk center (positive x is west, and positive y north.) Loops identified in the soft X-ray image are over-plotted in b-d.

Another obvious finding was that, except for simple bipolar regions, it was not a trivial exercise to identify coronal loops in SXT images. Far more regions are more complex than bipolar. Therefore, the identification of loops in a region like AR 7154 may be tricky (see Figure 5).

The 1992 dataset was unique in terms of coordination with ground-based observatories, including La Palma and Sac Peak. At Sac Peak, part of AR 7154 was observed in the CN band ($\lambda=3883$ Å), not frequently used lately. This line represents the height of ~ 300 km above the photosphere. Figure 6 compares various images of the inner part of the active region, including the CN image. It is clear that most bright features in C IV, H α , H β and CN correspond to magnetic enhancements (in (f)). In fact the bright features look similar in these images. It is still not clear, however, which ones correspond to the foot-points of hot loops. Loops are fuzzy in SXT images, and moreover, they must be twisted on the basis of the sigmoidal appearance. In addition, some of the bright pixels in the SXT images could represent emission from foot-points, making the comparison complicated.

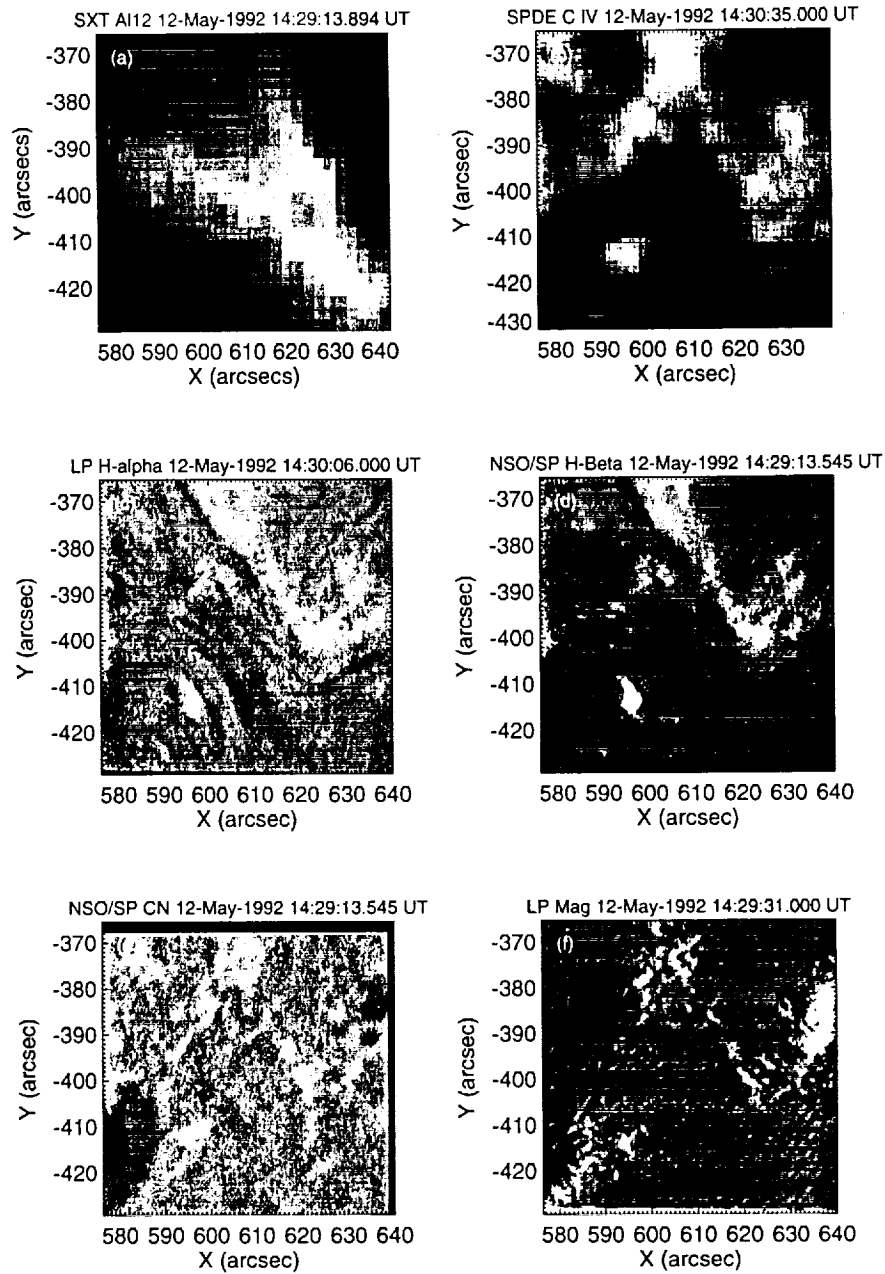


Figure 6: Close-up view of AR 7154. (a) SXT large-scale image. (b) SPDE C iv image. (c) H α image. (d) H β image. (e) CN image. (f) line-of-sight magnetogram.

Despite the general morphological similarity of the bright features in C iv and CN images, their intensity does not seem to be well-correlated. See Figure 7. Of course, the contribution from the temperature minimum region is not subtracted

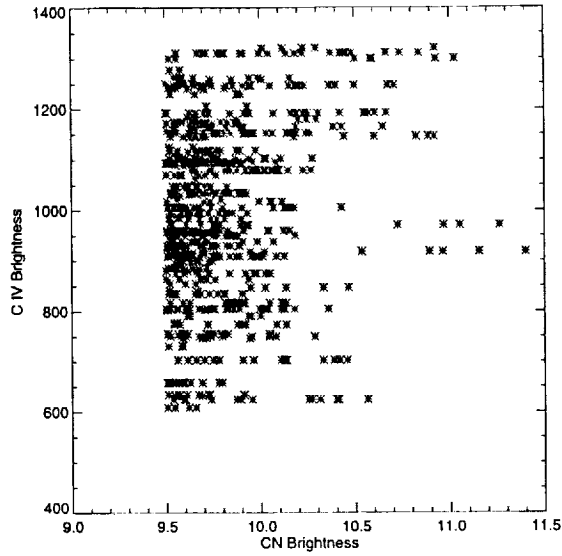


Figure 7: Scatter plot of the CN intensity and the C IV intensity for bright pixels in the CN image.

from the C IV image, but this lack of correlation may mean that the heat transport is complicated, and so is the magnetic field which channels the heat flow, between the heights of 300 km and 3000 km above the photosphere.

4 Large Scale Structure Study

We proposed a few topics that were included in this category. However, the study of coronal holes were found out to be better achieved with *SOHO*/EIT data. Therefore, we concentrated on the distribution of filament material in filament channels. Our initial idea was that the soft X-ray arcade and the H α filament is exclusive with each other.

We studied all the available magnetograms, X-ray and H α data and concluded that cancellation of magnetic flux towards the polarity inversion line is essential for filaments to form in the channel (c.f., Martin, 1998, Solar Phys., 182, 107). We see in Figure 8 that near the fragmented filaments mixed polarities are seen on one of the magnetograms, indicating that the areas are abundant in flux cancellation. Such cancellation is probably driven by flux emergence. One interesting aspect of these filament channels are that they are aligned almost east-west. Such a channel often corresponds to a distinct X-ray blob within a cavity as seen on the limb, similar to the one reported by Hudson et al. (1999, ApJ, 513, L83). Further observations of this phenomenon may be useful for understanding the relation among various structures in helmet streamers, including the hypothetical large-scale flux rope.

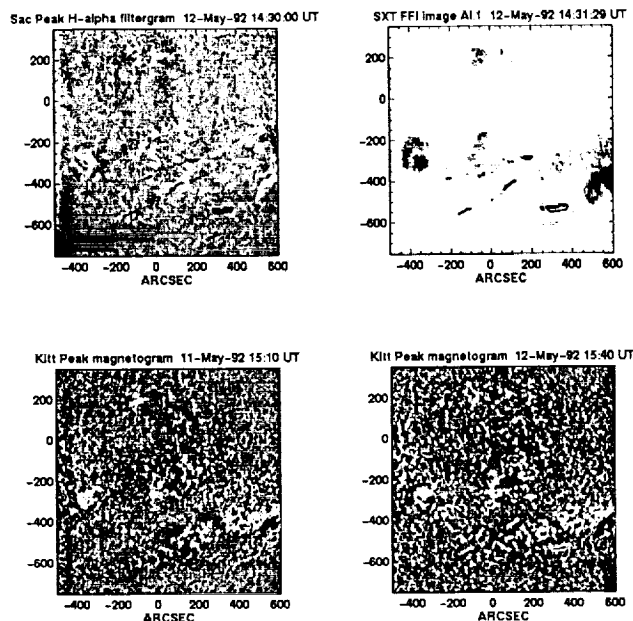


Figure 8: The $H\alpha$ filtergram showing filaments is compared with a soft X-ray image (in negative) and magnetograms from a day earlier and the same day. Solar rotation is corrected for on the magnetograms.

5 Other Activities

Although we still need more work, the information on the analysis of the SPDE data is on the Web (<http://macinnes.lmsal.com/contrast.htm>).

6 Publications

The following papers were completed in this period.

- Filaments and Magnetic Shear, M. E. Bruner and N. V. Nitta, submitted to Solar Phys in August 2000
- Identification of the Foot-points of Soft X-ray Loops in Solar Active regions, N. V. Nitta, M. E. Bruner, and W. A. Brown, submitted to ApJ (Letters) in August 2000
- Multi-wavelength Observations of Solar Active Region NOAA 7154, M. E. Bruner, N. V. Nitta, Z. A. Frank, L. Dame, and Y. Suematsu, submitted to Astron. and Astrophys. in August 2000

In addition, the following paper is now in print and will appear in Solar Phys. at any moment.

- The Relation between Hot and Cool Loops, N. Nitta, 2000, Solar Phys., in press

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